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APPLICATION FOR UNITED STATES PATENT

Title: **PERSONAL HEARING EVALUATOR**

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PERSONAL HEARING EVALUATOR

Background of the Invention

A. Technical Field

The present invention relates generally to air-conduction hearing evaluation, and more particularly, to portable hand-held hearing testing and hearing aid fitting.

B. Description of the Prior Art

Air-conduction hearing evaluation involves the presentation of airborne sounds (test stimuli) to the ears of a test subject. The evaluation may involve threshold measurements whereby the threshold of hearing is determined at various frequencies, or suprathreshold measurements whereby loudness perceptions above threshold are determined. Suprathreshold testing include *most comfortable loudness* (MCL*)*, *uncomfortable loudness* (UCL) and dynamic range measurements. A variety of test stimuli types are employed in audiological testing including pure tones, speech, and a variety of noise-based signals.

Test stimuli in air-conduction testing are emitted from a speaker to travel in air and ultimately reaching the eardrum. A speaker is typically positioned directly on or within the ear as in the case of circumaural earphones (headphones) and insert earphones. Alternatively, in sound field testing, a speaker is placed at a distance from the ear of the test subject in a test room (See American National Standard, specification for Audiometry, ANSI S3.6 -1996).

Sound field evaluation generally involves bulky instrumentation, complex calibration procedures and require specialized test rooms. Furthermore, precise positioning of the subject

with respect to a speaker is necessary in order to minimize errors in the intensity level of the sound at the ear. These errors are also caused by reverberations commonly found in test rooms (see Sandlin, R, Handbook of Hearing and Amplification, Ch. 6. pp 147-164, Singular Publishing group, 1995). Figs. 6-3 of Sandlin, for example, demonstrate how large the variability of pure tone sound field measurement can be for small changes in distance between the subject and the speaker.

In standard sound field audiometry, the subject is typically placed approximately at 1 meter (m) from the speaker. Unfortunately, the reverberant component of sound at 1 millimeter (mm) is significant as shown in Figs. 6-2 of Sandlin. The use of anechoic test rooms to eliminate reverberant sounds is extremely expensive and thus not employed in standard audiological test setups.

To minimize the effect of reverberant sounds, the subject should be positioned within the *direct field* of sound, which is typically within 70 centimeters (cm) from speaker. This causes the direct sound in the *direct field* to be dominant with respect to reverberant sound reflected from nearby objects in the room (i.e., walls, ceiling, floor, equipment, etc.). However, maintaining a precise seating arrangement within 70 cm of a speaker presents many challenges related to subject movement, discomfort, and even claustrophobia.

The utilization of probe tube microphone system to calibrate and regulate presentation levels has been widely used for various hearing evaluations (for example, see pp. 192- 204 in Sandlin). However, probe tube microphone instrumentation requires careful positioning of the probe tube for each hearing evaluation step performed. Furthermore, the use of microphone

probe tube systems adds considerable cost and complexity for the evaluation procedure, not to mention the inconvenience of attaching and maintaining a probe tube and its cabling for both the subject and the clinician.

In headphone audiometry (TDH-39 type for example), the distance between the test ear and the speaker is relatively stable thus alleviating the problem of speaker-subject positioning encountered in sound field audiometry. However, the headphone must be fitted in a sealing manner in order to minimize errors due to sound leakages that may occur at the headphone-ear contact area. Insert earphones (ER-3A type for example) also require a good sealing fit when inserted within the ear canal. Headphone and insert earphones can be uncomfortable and cumbersome for many individuals. Furthermore, headphone and insert earphones are particularly problematic for aided evaluation (with a hearing aid placed in the ear) because they generally interfere, physically and acoustically, with the proper function of a worn hearing device. Therefore, headphone and insert earphones are generally excluded from aided evaluation. Other problems associated with headphones and insert earphones include inaccuracies due to individual ear size variability and cabling interference and damage.

Portable and hand-held hearing evaluation is advantageous for conducting hearing testing outside the standard calibrated audiological setups. However, due to the relatively large errors associated with outside room acoustics, calibration, speaker-subject positioning and ambient background noise, portable and hand-held instruments tend to be limited to basic screening evaluation, requiring follow up testing in a proper audiological setup.

Review of state-of the-art in related hearing device technology

Heller, J., in United States patent Number (USPN) 4,567,881 describes a combination otoscope and audiometer for performing audiometric testing during otoscopic examination. Since the testing is performed while the tip of the otoscope is inserted in the ear canal, it is obviously not intended for aided evaluation whereby a hearing aid is worn in the ear canal. Furthermore, an otoscope is intended for use by a professional thus not suitable as a personal hearing evaluator.

Shennib, A. in USPN 5,197,332 describes a headset hearing tester which is worn on the head for positioning a speaker portion directly on the ear. As previously observed, headphone type audiometry not only interferes with the proper function of most hearing aids when worn, but is also bulky and uncomfortable for many users.

Chojar in USPN 5,081,441 discloses a hand-held tone generator for generating an audible tone as a test for equalizing binaural hearing aids. Chojar's device is limited to producing a single tone at single level, thus clearly not suitable for performing audiometric measurements. In fact, it is merely concerned with ensuring a balanced binaural aided hearing.

Downs, M., in USPN 5,291, 785 describe a hand-held portable device for testing infants for hearing defects. The device produces a low intensity sound for eliciting a response and a high intensity sound for eliciting reflex from the infant. Although designed to produce multi-level acoustic stimuli, the device is essentially a screening device for infants, thus not concerned with presenting accurate stimulus levels at multiple frequencies, nor concerned with aided evaluation. Furthermore, the device is clearly not designed for self-testing.

Posen et. al., in USPN 5,732,396 disclose a hand-held screening device for generating various acoustic stimuli at a distance set by a physical spacer incorporated into the screening device. The spacer makes direct contact with the ear area for positioning the speaker at 1 1/2 to 2 1/4 inches form the ear. The screening device, with a spacer incorporated within, has the advantage of providing a predetermined distance between the speaker and the test ear. However, the direct contact of the device to the ear area is not only awkward for audiometric testing, but is also difficult to operate by an individual of limited dexterity in self-testing scenarios. Furthermore, testing involving both ears simultaneously (binaural mode) is not possible with such a device.

There are numerous situations whereby it is desirable to provide a hand-held hearing evaluator with accurate multi-level test sounds. It is also desirable to provide a miniature instrument with means for self-administered testing without resorting to an expensive test performed by a hearing professional. In another situation, it is desirable to have a personal hearing evaluator to regularly verify the function of a worn hearing device. This is important since hearing aids are notorious for being subject to frequent damage and deterioration.

Therefore, it is a principal objective of the present invention to provide a hand-held hearing evaluation device for presenting multi-level and multi-frequency stimuli.

Another objective is to provide contactless means to properly position a speaker with respect to a test individual for accurate presentation of test stimuli.

A further objective is to provide a hearing evaluation device with means to automatically calibrate the level of acoustic stimuli presented.

A further objective is to provide an easy to use hand-held hearing evaluator suitable for self-administration by a test subject in either aided or unaided conditions.

Summary of the Invention

The invention provides a hand-held device comprising an audio transducer (i.e., speaker) for presenting acoustic test stimuli to a test subject within the direct sound field range of the device. The device delivers accurate multi-level and multi-frequency test stimuli for subjective response by the test subject holding the device. The battery-operated device is suitable for various hearing evaluation modes including aided (i.e., with a hearing aid worn) and unaided conditions.

In a preferred embodiment, the invention comprises an ultrasonic position sensor for measuring the position of the device with respect to the head of the test subject holding the hand held device. The distance is computed by measuring the latent period between the transmitted ultrasonic signal and the measured ultrasonic response reflected by the head or the ear. The acoustic test stimuli produced by the speaker are controlled and regulated based on the position of the device with respect to the test individual. Thus, the accurate levels of test stimuli are presented only upon the proper positioning of the device and irrespective of the exact position of the device. This eliminates position and movement-related errors commonly experienced in conventional sound field audiometry. Furthermore, the test subject or a test operator is automatically alerted whenever the device is incorrectly positioned during a test.

In an embodiment of the invention, the hand-held device is connected to an auxiliary

instrument (e.g., a computer or a microprocessor-based audiometer) for remotely controlling the device and for registering audible responses via a response switch provided on the invented device. In such embodiments, a test operator can select an acoustic test stimulus from a broader range of test stimuli. Thus, various threshold and supra-threshold tests are presented and responses are automatically registered by the auxiliary instrument.

In the preferred embodiment, the hand-held device is provided with at least two keys for selecting and presenting at least two stimulus levels. For example, the two keys may be an "S" key for presenting *Soft* level sound and a "C" key for presenting *Comfortable* level sound. The keys can be used by a test subject to routinely check the proper function of an in-situ (worn in the ear) hearing device. In another stand-alone embodiment, the hand-held device is used as an audiometric tool to assess hearing ability and specifically the need for a hearing aid use.

In the preferred embodiment, the device also provides switches for selecting one of at least two signal types such as *Noise* and *Speech* signals, and for selecting at least two frequency bands such as *Low* and *High* frequency bands. The combination of switches and key selections leads to a broad yet manageable range of test options, such as *Soft* level *High frequency Speech* or *Comfortable* level *Low* frequency *Noise*.

The device may be designed and configured for dual mode configurations by first being connected to an auxiliary instrument for performing relatively complex aided and unaided audiometric evaluation in the presence of a hearing professional, and subsequently as a personal evaluator for simple verification of hearing acuity and hearing aid function.

The device may be used for either binaural or monaural hearing evaluations. In binaural tests, the speaker of the device is oriented facing the forehead at a distance between 30-60 cm, depending on the individual's arm length. Although miniature and employing a miniature audio transducer, the device can produce high relatively intensity levels reaching 90 decibels (dB) sound pressure level (SPL) and more when positioned close to an ear (i.e., within few centimeters) in a monaural test mode.

Brief Description of the Drawings

The above and other objectives, features, aspects and attendant advantages of the invention will become further apparent from a consideration of the following detailed description of the presently contemplated best mode of practicing the invention, with reference to certain preferred embodiments and methods thereof, in conjunction with the accompanying drawings, in which:

Fig. 1 is a view of a preferred embodiment of the invention showing a hand held hearing evaluation device containing a speaker and position sensor system, both oriented towards the head of the user;

Fig. 2 is a more detailed perspective view of the hearing evaluation device of **Fig.1** being held in hand by a user;

Fig. 3 is a view of a dual-transducer position sensor for the embodiment of **Fig. 1,** having a transmitting ultrasonic transducer and a reception ultrasonic transducer;

Fig. 4 is a view of a single-transducer position sensor which is preferred for the

embodiment of **Fig. 1,** having a unitary transducer for both transmitting and reception of ultrasonic signals;

Fig. 5 is a block diagram of the major components within the presently preferred embodiment of the hearing evaluation device;

Fig. 6 is a view of the hearing evaluation device correctly positioned in range at 0° degree incidence angle with respect to the forehead of a user in a binaural test mode;

Fig. 7 is a view of the hearing evaluation device being incorrectly positioned out of range and oriented at an unacceptable incidence angle with respect to the forehead of a user in a binaural test mode;

Fig. 8 is a view of the hearing evaluation device being correctly positioned at 0° degree incidence angle with respect to an ear of a user in a monaural test mode;

Fig. 9 is a view of the hearing evaluation device also being correctly positioned at 45° degree incidence angle with respect to an ear of a user in an alternate monaural test mode;

Fig. 10 is a view of the hearing evaluation device of the present invention connected to an auxiliary instrument;

Fig. 11 is a view of the hearing evaluation device held by a test operator directing the speaker at a test subject; and

Fig 12 is an embodiment of the hearing evaluation device incorporating a control magnet within its housing to remotely control the function of a hearing aid worn in the ear canal.

Detailed Description of the Preferred Embodiments and Methods

The present invention, shown in **Figures 1-12**, provides a personal hearing evaluation device **10** for accurately presenting multi-level acoustic test stimuli (sounds) to an individual via an audio transducer (i.e., speaker) **11** incorporated within the housing of the device. The invented device **10**, as shown in **Figs. 1** and **2**, is designed for holding by hand and for directing sound **13** from its speaker **11** towards an ear **3** of a user **1** in a contactless manner but within the direct sound field range of the speaker. In the preferred embodiments, shown in **Figs. 1-11**, the device **10** comprises a position sensor **12** for automatically measuring the position of the device **10** with respect to the user's head **4**, or a part thereof of interest, depending on the test mode as described below. The device **10** also comprises keys (switches, e.g., **61** and **62, Fig. 2**) for selecting at least two levels of sound **13**, presented in the direction of an ear (monaural mode, **Figs. 8** and **9**) or both ears (binaural mode, **Figs. 6** and **7**).

The position sensor **12** incorporated in the preferred embodiment of the invented device produces incidence wave **14** (solid arrows) which partially bounces off the head, or a part thereof (i.e., nose, forehead, chin, ear, etc.), and becomes a reflected wave **15** (dashed arrows) for reception by the position sensor **12**. The position sensor **12** in the preferred embodiment comprises one or more ultrasonic transducers. **Fig. 3** shows a position sensor **12** employing a pair of ultrasonic transducers. The first transducer is a transmitter **20** for emitting incident wave **14**, and second transducer is a receiver **22**, for receiving the reflected wave **15** bouncing off the head or a part thereof. The transmitter **20** and receiver **22** transducers further employ directional filters, **21** and **23**, respectively, for appropriately directing the incident wave **14** and

receiving reflected wave **15**. These filters improve the reception and directionality of the position sensing process for ensuring proper positioning of the device with the respect to the individual.

In a preferred embodiment of the position sensor, shown in **Fig. 4**, a unitary ultrasonic transducer **12** (for example, piezoelectric transducer model ITC-9073 manufactured by International Transducer Technology, Inc.) is employed both for transmitting incident wave **14** and for receiving reflected wave **15**. This unitary transducer design consumes less space and thus is more suited for the miniature battery-operated design of the hearing evaluation device of the invention.

Figure 5 shows a block diagram of an exemplary embodiment of the personal hearing evaluation device **10**. A controller **30** (i.e., microprocessor, microcontroller, etc.) is employed to perform various computational and control processes as will be described below. Memory **50** is employed to store program data (not shown) and test stimulus data (**51** and **52**) in digital format representative of acoustic test stimuli to be presented by the speaker **11** upon request by the test subject **1** or a test operator **8** (**Fig. 11**). Test stimulus data may be representative of speech words **51** (**Fig. 5**), noise **52** and any other signal which is of audiological significance (not shown) such as pure tone, warble tone, chirp, etc. Test stimulus data is retrievable from memory **50** by the controller **30** for conversion into analog signal **41** by the digital to analog (D/A) converter **40**. The analog signal **41** is then delivered to a programmable volume control **42** and then to a power amplifier **43** for providing speaker input signal **44** to the speaker **11**. Test sound **13** is finally produced by speaker **11** and directed towards the test subject **1**

positioned in the direct sound field range as shown in **Fig. 1**.

The block diagram of **Fig. 5** also shows position sensor **12** (an ultrasonic transducer) which transmits ultrasonic incident wave **14** and receives ultrasonic reflected wave **15** from the head or the ear of a test subject **1** (**Fig. 1**). The controller **30** is also connected to transmission circuitry **31** (labeled TRX circuitry in **Fig. 5**) and reception circuitry **32** (labeled RX circuitry in **Fig. 5**) for processing of signals sent and received during the process of position sensing. The microcontroller **30** is also connected to a switch array **60** (switches, keys, etc.) for selecting and presenting acoustic stimuli upon the request of a test subject **1** or a test operator **8** (**Fig. 11**).

A typical cycle for the position sensing process is automatic and begins when the controller **30** receives an actuation signal from a key (part of the switch array **60**). The appropriate pattern of initial transmission signal **33** is produced by the controller **30** and fed into the transmission circuitry **31** which produces an output transmission signal **35** causing the position sensor **12** to transmit an ultrasonic incident wave **14** towards the head or ear of the test subject. A properly positioned head or ear with respect to the device will cause a reflected wave **15** to be received by the position sensor **12**, which produces incoming reception signal **36**. Reception circuitry **32** processes the incoming reception signal **36** and delivers a filtered reception signal **37** to controller **30**. The latency period -- the time between the onset of signal transmission and reception -- is employed by the controller **30** to compute the position of head or ear with respect to the device **10**. The above mentioned process is typically performed in repeated bursts or packets of sensing signals, according to an appropriate detection algorithm,

for determining the correct position of the device in the presence of possible noise and interference.

Upon proper positioning of the device by the position sensor system (in **Fig. 5** comprising ultrasonic transducer position sensor **12**, transmission circuitry **31**, reception circuitry **32** and microcontroller **30**), the device **10** delivers an acoustic test stimuli via speaker **11** to the test subject **1**. It will be understood, of course, that although the incident wave **14** delivered by position sensor **12** and the test stimulus delivered via speaker **11** to the test subject appear to be directed in opposite directions in the block diagram of **Fig. 5**, this is simply for the sake of convenience of block diagrammatic representation and they are actually delivered in the same general direction as indicated in **Figs. 1** and **2**. The automatic position sensing process is relatively rapid and typically occurs within 100 milliseconds (ms) after pressing a stimulus request key. Therefore, the onset of a test stimulus is essentially perceived "instantaneously" by a test subject.

However, if the positioning of the head is determined improper by the position sensor system (i.e., out of range, improper orientation, reverberant environment, etc.), the device presents the appropriate alarm indicator to the user. **Fig. 2** for example shows an alarm light indicator **71** in the form of an LED (light emitting diode). Alternatively, a LCD (liquid crystal display) or even distinct audible sounds (i.e., buzzer-like) may be employed to alert the user of an improper positioning or function of the invented device. Display elements are collectively shown as LED/Display **70** in **Fig. 5**.

The device in the embodiment shown in **Fig. 5** also incorporates a microphone **16** for

sensing the ambient background noise **17** and ensuring acceptable noise levels prior to delivering a test stimulus. For example, the onset of a test stimulus may be automatically delayed or canceled if the ambient noise level was measured to exceed the level of an intended test stimulus. In another example, the level of intended test stimulus may be automatically increased to ensure acceptable signal to noise (S/R) ratio. The microphone may also be used for self-testing or auto-calibration of the device by sensing a calibration signal (not shown) delivered by the speaker **11** and comparing its measured characteristics to a predetermined pattern stored in memory **50**. The microphone signal **39** from the microphone **16** is amplified by microphone signal amplifier **38** and delivered to controller **30** for digital sensing and computation. An analog to digital converter (not shown) is preferably employed, within the microcontroller **30** or as a separate component within the device, in order to convert microphone signals and various analog signals within the device into a digital format for interpretation and computation by the controller **30**. A battery **27** is provided to power the portable hearing evaluation device **10** of the present invention.

Figure 6 shows an example of a binaural test mode of the hearing evaluator device **10** positioned within proper range **60** and orientation (0° degree incidence angle) with respect to the user's forehead **4**. Sound, **13** and **13'**, from speaker **11** is directed at right **3** and left **3'** ears, respectively. A sufficient portion of incidence wave **14** transmitted from position sensor **12** is reflected back (reflected wave **15**) to the position sensor **12** causing reception signal **37** (**Fig. 5**) of sufficient strength and latency for proper detection by the position sensing system. The distance of the device with respect to the forehead is preferably in the range of 30-60 cm to

accommodate the arm length range of individuals holding the device as shown in **Figs. 1** and **2**.

Figure 7 shows an example of a binaural test mode with device **10** being incorrectly positioned outside the proper range **60** and also being incorrectly oriented with respect to the forehead **4** of the user **1**. Since the incident angle θ **(61)** is much greater than 0° degree, the incident wave is minimally reflected, if at all. However, even if a fringe incident wave **14'** is reflected causing a fringe reflected wave **15'**, the reception signal **37** is insufficiently weak as determined by the position sensor system.

In the binaural test mode, shown in **Figs. 6** (correct) and **7** (incorrect), both ears are typically involved in the hearing evaluation process. However, if only a single ear is to be tested in this mode, the other ear must be excluded by an appropriate method such as by occluding the non-test ear or by turning off a hearing aid worn in the non-test ear.

Fig. 8 shows a preferred method for monaural hearing evaluation. The invented device **10** is placed within exceptional proximity to a single test ear **3** (right). In this monaural test mode, the device is placed within a 2-10 cm range from the ear and oriented at incidence range of 0°- 45° degrees. **Fig. 8** shows device placement at 0° degree incidence with respect to right ear **3**. **Fig. 9** shows device placement at 45° degrees incidence with respect to a left ear **3'**.

Fig. 2 shows a perspective view of an exemplary embodiment of the hearing evaluation device **10** being held by hand **5** of a test subject (**1** in **Fig. 1**). The device **10** comprises a first key **61** configured for pressing by the thumb **6** and a second key **62** configured for pressing by the index finger **7**. The speaker **11** is oriented towards one or both ears as shown in **Figs. 6-9**

and described above. Light Emitting Diodes (LED), **71** and **72**, are employed to provide visual indications to the test subject **1**. For example, an alarm LED **71** (typically a red light) is provided to indicate incorrect positioning of the device. LED **72** (typically a green light) may be used to indicate valid "OK" operation or charged battery. A directional filter **21** is fitted over the position sensor **12** to improve the directionality of incident wave **14**, reflected wave **15**, or both. A speaker cover **45** with holes **46**, or an acoustically transparent structure (not shown), are provided to protect the speaker **11** within while allowing test sound **13** to pass through towards the test subject.

Fig. 2 also shows a first switch **25** (two-position switch) for selecting one of two signal types; speech (marked SP) or narrow-band-noise (marked NBN). A second switch **26** (three-position switch) provides selection of one of three frequency bands; low, medium or high (labeled LF, MF and HF, respectively). Keys, **61** and **62**, are employed to select at least two levels of sounds. In the preferred embodiment, these two keys present soft and comfortable sound levels, both with respect to normal hearing individuals. Soft sound key **62**, for example, (marked "S") preferably presents a fixed level sound in the range of 20 to 40 dB HL (hearing level). Comfortable sound key **61**, for example, (marked "C") preferably presents a fixed level sound in the range of 45 to 60 dB HL.

The exemplary key and switch configuration of the device **10** in **Fig. 2** leads to a combination of 12 individual test stimuli (2 keys x 2 positions x 3 positions) for performing various hearing evaluation tests. The accuracy of each test stimuli presented is ensured and regulated by the position sensor system incorporated within as described above. For example,

if the speaker-head distance is measured (automatically) to be at 50 cm (i.e., binaural test mode), the speaker input signal 44 (Fig. 5) is then automatically ~~reduced~~ increased relative to a condition where the speaker-ear distance is at 5 cm (i.e., monaural test mode). This automatic adjustment (auto-calibration) is necessary in order to produce an equal perception of loudness at the ear, irrespective of the test mode or the exact position of the speaker **11**.

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In addition to the automatic level adjustment affecting the speaker input signal, the frequency characteristics of the test sound may also be manipulated in order to minimize inaccuracies associated with frequency-dependent stimulus. In pure tone test sounds, for example, it may be desirable to slightly shift the test frequency in order to minimize the affects of standing waves. A slight shift in the frequency is considered acceptable in audiological standards for most audiometric evaluations. For example, ± 1% and ± 3% frequency variation is permissible for type 1 and type 4 audiometers, respectively, according to ANSI S3.6, 1996.

The types of test signals possible with the present invention are not limited to speech, pure tones or narrow-band-noise. Virtually any signal of audiological significance may be reproduced from a digital recording, or synthesized, by the microcontroller for the presentation to the test subject. Other possible signal types include warbled tones, white noise, chirp (sine-wave composition), speech noise and other frequency weighted signals.

The hearing evaluator of the present invention, although miniature and employing a miniature audio transducer (speaker) **11**, can produce sound at significant intensity levels when positioned within close proximity to a test ear as shown in **Figs 8** and **9**. In this monaural test mode, the intensity levels of test stimuli at the ear can reach 90 dB-SPL (sound pressure level)

or more while consuming little energy available from standard batteries. For example, a 98.3 dB-SPL tone at 4000 Hz. was produced at the ear from a miniature high fidelity speaker (model 4D06C manufactured by Panasonic) when positioned approximately 5 cm from an individual's ear (monaural test mode Fig. 8). The speaker input signal voltage to produce the 98.3 dB at 5 cm was measured at 0.7 Vrms. The power into the speaker measured at about 0.05 watt, which is readily available from standard batteries. Loud level sounds at 90 dB-SPL are particularly useful in assessing the aided hearing function of an individual during the fitting process to ensure comfortable hearing when the hearing aid is subjected to loud sounds. If found too loud by the aided test subject, the maximum output of the hearing aid must be reduced to a more acceptable level.

The same speaker input signal level (0.7 Vrms) produced only 82.5 dB-SPL at the ear when the speaker was positioned at 40 cm. Obviously, by scaling down the speaker input signal, soft and even threshold level sounds can be readily produced at virtually any distance within the preferred usable range of 2 to 60 cm. The above sound pressure level measurements at the ear were taken by probe-tube microphone system (model ER-7C, manufactured by Etymotic Research).

The personal hearing evaluator device **10** can be used by a test subject **1** to conduct a self-administered screening evaluation (pass/fail test) using the keys provided on the device.

The device in the above-described preferred and alternate embodiments can also be used in a professional setup during the fitting process of a hearing aid. For example, in the unaided condition and prior to hearing aid selection, the threshold of hearing of an individual (test

subject) is determined at various audiometric frequencies. Later on, the hearing evaluation is performed while a hearing aid is *in situ* (worn in the ear or the ear canal). In this aided condition, adjustments to the in-situ hearing aid are made while the test subject responds to the sound field stimuli produced by the hand-held device of the present invention. For example, soft level gain, compression ratio, maximum output, frequency response, attack time and any other parameter of a hearing aid, may be adjusted based on the test sounds produced from the speaker of the hand-held device. Following the fitting process, the test subject can use the hearing evaluation device **10** as a personal hearing evaluator. For example the acuity of the aided hearing can be checked regularly by the user at home by pressing the soft level key (**62** in **Fig. 2**) to present soft level sounds (audible by normal hearing individuals). This is important because hearing aids tend to gradually deteriorate with time due to moisture or earwax contamination. A regular check-up by the hearing evaluation device of the invention should detect possible changes in either the hearing aid or the hearing ability of the user.

In the above-described embodiments, the hand-held hearing evaluation device is described in stand-alone configurations for use in unaided or aided conditions. **Fig. 10** shows an alternate embodiment of the device **10** connected to an auxiliary instrument **80** (shown as a computer or computer-based instrument). The elongated hand-held device **10** is provided with an interface port **28** (also shown in **Figs. 2** and **5**) for connecting to auxiliary instrument **80** via the connection cable **81** and its electrical plug **82** inserted into interface port **28** of the device **10**. The auxiliary instrument **80** is used by a test operator to control the device **10** by sending the appropriate control commands to the controller **30** (**Fig. 5**) of the device via

auxiliary interface circuitry **48 (Fig. 5)**. This auxiliary control mode available by the present invention allows a test operator (other than the test subject holding the device **10**) to remotely control the function of the device **10**. One advantage of this mode is to allow the operator to select a test stimulus from a broader range than possible with the device in its stand-alone configuration (having relatively a limited number of key and switch selection). The remote control interface mode is useful, for example, in performing a more comprehensive hearing evaluation such as for conducting a complete audiogram test involving 6 or more frequencies. In the remote control mode by an auxiliary instrument **80**, a key (such as key **61** or key **62**) within the device **10** can be used as a response key to register responses of the test subject and relay such registration to auxiliary instrument **80** when the test subject hears and presses the response key.

The auxiliary instrument **80**, in conjunction with a response key on the device, can be used to automate the presentation of a hearing test according to procedures and protocols known in the field of automated audiometry. Furthermore, the auxiliary instrument **80** may be used to program the connected device **10** to perform specific test or function according to the needs of the individual test subject. The auxiliary instrument **80** may be a computer as shown, a microprocessor-based audiometer instrument (not shown), or any other suitable control instrument. The connection between the auxiliary instrument **80** and the device **10** may be via a direct wire as shown in **Fig. 10**, or via a wireless connection (not shown) as widely known in the field of wireless control and communications.

The auxiliary instrument mode is ideally suited during the initial fitting evaluation at the

site of the hearing aid dispensing professional. For example, a test operator (audiologist, doctor, nurse, etc.) can perform various unaided and aided evaluation on a test subject holding the device by hand. Once the hearing aid fitting process is completed, the hand-held device **10** is then disconnected from the auxiliary instrument **80** and offered to the test subject as a personal evaluator. Similarly, the personal evaluator device **10** can be used to regularly verify the proper function of an in-situ hearing device. The personal evaluator device **10** comprises a battery **27** for powering the device in its stand-alone mode after being disconnected from the auxiliary instrument **80**.

The auxiliary instrument mode is also suited for remotely administering a hearing test when the subject is remotely present and the device is connected to the appropriate network. For example, a hand-held device **10** can be directly connected to a computer which is also connected to a remote computer (auxiliary instrument) via the Internet. This way, a hearing professional can remotely administer a test to a test subject, present at home for example. In this case, the test subject simply connects the hearing evaluation device **10** to a computer port (not shown) of a personal computer connected via the Internet to the computer of the hearing professional. Other remote interface methods are possible and conceivable as will become obvious to those skilled in the art of computers, communications and networking.

The invented device **10** is highly portable and configured for easy transport and convenient hand-held operation as described in the above embodiments. For example, the device in **Fig. 2** is shown resembling a hand-held stopwatch or a garage-door opener. In **Fig. 10** the device **10** is shown resembling a pen. Other designs, well within the scope of this

invention, include wristwatch **95** (**Fig. 13**) and other configurations, which will become obvious to those skilled in the art of miniature personal instrument design.

The invented device **10**, although most suitable for holding by a test subject who orients the speaker towards his or her own ears, it may be desirable in certain conditions for a test operator (a hearing professional, parent, spouse, etc.) to hold the device **10** and assist in conducting a hearing test. This may be necessary for testing young children, persons with poor dexterity, and other difficult to test individuals. **Fig. 11** shows a test operator **8** holding the hearing evaluation device **10**. Similarly, the test sound **13** and the incident wave **14** of the position sensor **12** are directed towards the head **3** of the test subject **1** to properly deliver acoustic test stimuli to one or both ears of the test subject **1**.

The personal hearing evaluator may incorporate wireless remote control means for remotely controlling or programming a hearing aid. For example, hearing aid volume can be remotely adjusted, or the power may be remotely turned on or off. Wireless control means are widely known in the field of hearing aids and include ultrasonic, electromagnetic, sonic, magnetic and infrared signals. In a preferred embodiment shown in **Fig. 12**, the hearing evaluator device **10** comprises a magnet **18** having a magnetic field **19** which remotely, but within close proximity, controls a hearing aid **90** positioned in the ear canal **7**. The magnetic field **19** may be reversed in its direction (not shown) simply by flipping the device and thus reversing the polarity of the magnet **18** within. The details of such magnetic control operation are disclosed in a pending patent application Serial No. 09/181,533 of the same inventor, filed October 28, 1999 and incorporated herein by reference. The magnet typically employed within

a speaker **11** transducer may be relied on for such remote control application thus eliminating the need for an additional magnet.

The position sensor system in the preferred embodiments, described above, employ ultrasonic transconduction for sending and receiving ultrasonic waves. However, other contactless position sensing means are possible and may be equally suitable as known by those skilled in the art of proximity and position sensing. For example by employing optical transducers (i.e., infrared LED) in conjunction with appropriate directional optical filters. In another example, a sonic wave produced by the speaker **11** may be utilized for position sensing.

Although a presently contemplated best mode of practicing the invention has been described herein with reference to certain presently preferred and alternate embodiments and methods of use, it will be recognized by those skilled in the art to which the invention pertains from a consideration of the foregoing description, that variations and modifications of these exemplary embodiments and methods may be made without departing from the true spirit and scope of the invention. Thus, the above described embodiments of the invention should not be viewed as exhaustive or as limiting the invention to the precise configurations or techniques disclosed. Rather, it is intended that the invention shall be limited only by the appended claims and the rules and principles of applicable law.